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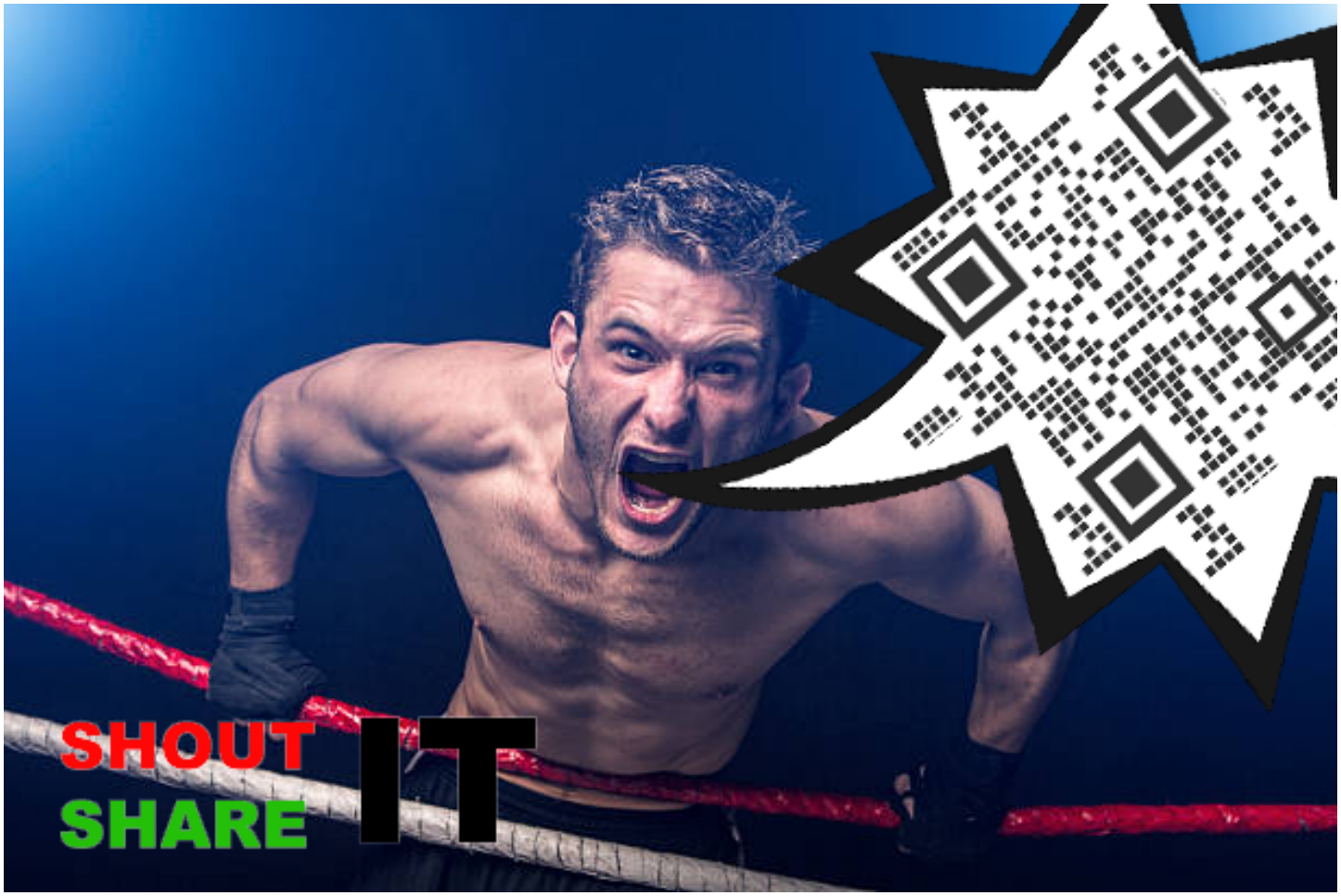
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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 249

Contribution from the Office of Public Roads
LOGAN WALLER PAGE, Director

Washington, D. C. ▼ July 26, 1915.

PORTLAND CEMENT CONCRETE PAVEMENTS FOR COUNTRY ROADS

By

CHARLES H. MOOREFIELD and JAMES T. VOSHELL
Senior Highway Engineers

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INTRODUCTION.

The purpose of this paper is to supply reliable information on the subject of Portland cement concrete pavements for the use of highway engineers and others interested in the improvement of public roads. It is realized, however, that the present state of knowledge concerning the best methods of constructing such pavements is by no means complete, and those who have charge of concrete-road construction should be careful to keep themselves informed regarding results obtained by others engaged in similar work and by laboratory experiments.

The earliest concrete pavement in the United States of which there is reliable record was constructed at Bellefontaine, Ohio, during 1893 and 1894. This pavement contains 4,400 square yards and was constructed in squares similar to those employed in concrete sidewalk construction. The concrete was laid in two courses. This early experiment indicated many possibilities and no doubt has been responsible for some of the construction methods in use at present. Prior

NOTE.—This bulletin contains reliable information on the construction of Portland cement concrete pavements for country roads. Practical instructions for highway engineers and all others interested in road making are given.

to 1909 the total area of concrete pavements which had been constructed in this country was comparatively small, and in the majority of cases these pavements were frankly regarded as experiments. During 1909 the road officials of several communities concluded that the results already obtained were sufficiently encouraging to warrant them in undertaking the construction of concrete roads on a larger scale, and since that time many such roads have been completed. Wayne County, Mich., was one of the first communities to adopt this form of construction and at present probably has a greater mileage of roads paved with concrete than any other county in the United States.

The fact that the majority of the concrete pavements which have been constructed have proved entirely satisfactory where traffic conditions were not unduly severe is serving to increase their popularity very rapidly. This is evidenced by the following tabulation, showing the approximate number of square yards of such pavements that have been constructed in the United States each year beginning with 1909:

	Square yards.
1909	364,000
1910	850,000
1911	1,800,000
1912	6,470,000
1913	10,100,000
1914 (estimated)	19,200,000

Enthusiastic advocates of concrete roads should bear in mind that such roads can never be economically adapted to all traffic conditions, and those who are in responsible charge of road-improvement work should realize the importance of making a careful economic comparison of the various kinds of road surfaces under the conditions to be met before deciding upon the type of improvement to adopt.

The principal advantages which concrete pavements possess may be briefly stated and commented upon as follows:

1. As far as can be judged, they are durable under ordinary suburban and rural traffic conditions. While it is true that there are no very old concrete pavements in existence, the present condition of many of those which have undergone several years' service would seem to warrant the above statement.

2. They present a smooth, even surface, which offers very little resistance to traffic. In the past the surfaces of concrete pavements have sometimes been roughened in order to insure a good foothold for horses. This practice has now been abandoned, except on very steep grades, because it tends greatly to accelerate deterioration of the pavement, and because the smooth surface has been found to afford a fairly satisfactory foothold under all ordinary conditions.

3. They produce practically no dust and may be easily cleaned.

4. They can be maintained at comparatively small cost until renewals become necessary.

5. They may be made to serve as an excellent base for some other type of surface when resurfacing becomes desirable.

6. They present a pleasing appearance.

The principal disadvantages are:

1. They are somewhat noisy under horse traffic.

2. There is no method of constructing necessary joints in the pavements which will entirely prevent excessive wear in their vicinity. Furthermore, joints do not altogether eliminate cracking, and wherever a crack develops it must be given frequent attention in order to prevent rapid deterioration of the pavement.

3. They can not be as readily and effectively repaired as many other types of pavements.

MATERIALS AND CONSTRUCTION.

It is especially desirable that concrete for road pavements should possess, in as great degree as practicable, (1) hardness, in order to resist the abrasive action of traffic; (2) toughness, in order to resist the disintegrating action of horses' hoofs and other shocks; and (3) homogeneity, in order that the surface may wear uniformly.

The character of the constituent materials and the proportions in which they are mixed both have a marked influence on the degree in which these qualities are possessed by the concrete. In selecting the materials and determining the proportion in which they are to be mixed, the prospect of securing the desired qualities in the resulting concrete should be given primary consideration. The methods of mixing, depositing, and curing the concrete are also important factors in securing satisfactory results and will be discussed in their proper places.

MATERIALS.

No hard and fast rules can be laid down which would fit all cases in the selection of concrete materials, as availability is necessarily a very important factor. Satisfactory cement can usually be obtained, and none should be used in constructing pavements which does not meet all the requirements for a high-grade Portland cement. The cost of importing the sand and coarse aggregate from any considerable distance is usually prohibitive, and if there are any local materials which are or can be made suitable for aggregates they should be given first consideration. But if the local materials are not such as to meet substantially the requirements outlined in the following paragraphs, it would be very doubtful economy to use them.

CEMENT.

Portland cement of a character satisfactory for use in pavement construction is at present manufactured in nearly every section of the country. The product of all cement plants is not always entirely uniform and of equal excellence, and even if it were uniform immediately after manufacture this condition might easily be changed by age or exposure. These facts make it imperative that cement for use in concrete pavements be subjected to very rigid inspection. It should be known to conform to the requirements of some standard specification for Portland cement, such as that contained in Circular 33 of the United States Bureau of Standards or that issued by the American Society for Testing Materials.

SAND.

Sand for use in concrete pavements should be selected with especial care. The strength of mortar depends almost, if not quite, as much on the quality of the sand used as on the quality of the cement, and a strong mortar is imperative if the best results are to be obtained. Preference should be given to sand composed of a mixture of coarse and fine grains, with the coarse grains predominating, though sand consisting entirely of coarse grains is preferable to that in which the fine grains predominate. It is also very important that the sand be as clean as practicable. Sand which contains more than about 3 per cent of foreign materials, such as loam or clay, should be rejected, and no sand should be used the grains of which are coated with clay or other objectionable material.

Sand which contains even a very small percentage of vegetable acids is unsuitable for use in concrete, because such acids seriously affect the strength of cement. It is not always easy to detect the presence of acids in sand, and in order to insure that they are not present in any great extent it is well to specify that cement mortar in which the proposed sand is used will develop a tensile strength equal to that developed by mortar made of the same cement and standard Ottawa sand.

COARSE AGGREGATE.

The coarse aggregate may consist of either crushed stone or gravel. It has been claimed that the angular shape of the particles of crushed stone gives that material an advantage over gravel in the matter of securing a satisfactory bond with the mortar of the concrete, and this claim seems to be at least partially justified by experience. Wherever gravel and crushed stone have been used as coarse aggregates in different sections of the same pavement, and the different

sections have been given identical treatment, a proportionally greater number of cracks have usually formed in the gravel concrete. It has been observed, however, that when some varieties of stone are used as coarse aggregate the resulting concrete shows very little, if any, superiority over gravel concrete as regards the formation of cracks. It therefore seems possible that the quality of stone, rather than the angular shape of the particles, may be responsible for the apparent advantage of crushed stone over gravel.

There are not sufficient data available to warrant making a definite comparison of the advantages possessed by the different varieties of stone when used as coarse aggregate. But so far as cracks are concerned, limestone appears to have made a better record than any other variety of stone which has been used to any considerable extent.

The coarse aggregate, whether of crushed stone or gravel, should possess at least as great resistance to wear as the mortar which fills the voids between the particles of stone. Any sound stone or gravel, moderately hard and tough, will meet this requirement, but in general the harder and tougher the coarse aggregate, the greater the resistance to wear of the concrete. The best available stone should therefore always be used.

The difficulties experienced in securing a satisfactory quality of coarse aggregate are frequently caused by a lack of proper facilities for preparing the natural materials locally available. There are very few gravel pits which furnish a gravel suitable for use in concrete pavement construction without washing, and properly equipped washing plants are both difficult and expensive to construct. On the other hand, a great many stone quarries contain pockets of clay or inferior stone which should not be contained in the aggregate, and it is sometimes very difficult to remove these objectionable materials while the stone is being crushed and screened. It is also frequently difficult to screen out the dust of fracture formed in crushing some varieties of stone.

It is very desirable that the particles composing the coarse aggregate be well graded in size between proper limits in order that the percentage of voids may be as small as practicable. It is convenient to fix the limit of variation by specifying a certain screen upon which coarse aggregate shall all be retained, and another screen which it shall all pass. A ¼-inch mesh screen for the lower limit and a screen having 1½-inch circular openings for the upper limit have been most frequently specified for coarse aggregate used in concrete pavements. The upper limit of 1½ inches seems to be entirely satisfactory in nearly all cases, but the lower limit of ¼ inch frequently results in a failure to remove as much fine material from the aggregate as is desirable. For example, when the coarse aggregate is se-

cured from gravel containing a considerable percentage of sand, or from crushed limestone, a $\frac{3}{8}$-inch mesh minimum screen is to be preferred.

WATER.

Water used in mixing concrete should be reasonably clear and free from alkalies, acids, vegetable matter, or other injurious materials. The subject of water supply will be later discussed under the heading, "Methods, organization, and equipment."

PROPORTIONING.

Concrete in pavements is subjected to much more severe service conditions than that in walls, foundations, etc. Most of the old rules for proportioning concrete were developed with a view to providing only for simple compressive stresses, such as are met with in the latter class of structures. Hence it is not surprising that the early results obtained for pavements by following the old rules were not generally satisfactory. Concrete pavements must resist not only crushing and impact stresses but the wearing action of traffic as well, and this is probably the most destructive process to which they are subjected.

The essential qualities which enable any material to withstand the wearing action of traffic are hardness and toughness. Laboratory tests have been devised for determining the relative degree in which these qualities are possessed by different kinds of stone and brick, but none of these tests is suitable for making similar determinations regarding concrete mixed in different proportions and composed of different materials. The reason for this is that the structure of concrete, unlike that of ordinary stone and brick, is not homogeneous. It is possible, however, to employ the routine road-material tests described in Office of Public Roads Bulletin No. 44 on the mortar and coarse aggregate separately, and it would seem that the results which might be obtained in this way ought to furnish a fairly reliable index to the quality of concrete which could be produced from the materials tested. The proper proportions in which to mix the materials can probably be best determined from actual service tests.

Plates VII, VIII, and IX are diagrams showing the relative hardness, toughness, and crushing strength of mortars mixed in different proportions and in which two different qualities of sand were used. Sand for one set of the test specimens, as noted on the diagrams, was standard Ottawa, while that for the other set was natural quartz sand which showed the following analysis:

TABLE I.—*Granulometric analysis of quartz sand.*[1]

Size of grains.	Grams.	Per cent.
Retained on—		
¼-inch mesh screen	0.0	0.0
⅛-inch mesh screen	74.0	5.9
No. 10 screen	124.5	10.0
No. 20 screen	266.0	21.2
No. 30 screen	460.0	36.7
No. 40 screen	624.0	49.8
No. 50 screen	930.5	74.3
No. 80 screen	1,139.5	91.1
No. 100 screen	1,159.5	92.7
No. 200 screen	1,198.5	96.5
Passing a No. 200 screen	51.5	3.5
		100.0

[1] Total weight of sample, 1,250 grams; weight of sample after washing, 1,208 grams.

Experience has shown that when first-class sand is used very good results are obtained by using a proportion of 1 part of cement to $1\frac{1}{2}$ or $1\frac{3}{4}$ parts of sand and making the proportion of coarse aggregate such that the resulting concrete will contain slightly more mortar than is sufficient to fill all voids. If a well-graded gravel is used as coarse aggregate, the proportion should be about $1:1\frac{1}{2}:3$, while in most cases where broken stone is used as coarse aggregate it will be found desirable to make the proportion about $1:1\frac{3}{4}:3$, and in some cases, where the particles of stone are of uniform size, even a still greater proportion of mortar will be required, but this should be effected by decreasing the amount of coarse aggregate and not by further increasing the amount of sand.

Since the bottom course of a two-course pavement is not subjected to the wearing action of traffic, it would appear that the rules for proportioning the materials for this course might be considerably modified. On the other hand, using different proportions in the top and bottom courses undoubtedly results in the concrete of the two courses having different coefficients of expansion and different moduli of elasticity, and these differences might tend to cause a separation of the two courses. The fact that such separations sometimes occur strengthens this theoretical objection.

CONSTRUCTION.

TYPES.

There are two general types of concrete pavement, known as the one course and the two course. These designations are due to the fact that the former consists of one course of concrete, all of which is mixed in the same proportion and composed of the same kind of materials, while the latter consists of two courses of concrete, usually mixed in different proportions and containing different kinds of aggregate. Plate X, figure 1, shows a typical cross section for a

concrete pavement, and this general form is suitable for either one-course or two-course work. The one-course pavement is somewhat simpler to construct than the two-course type. It possesses the advantages that there is no possibility for the wearing surface to separate from the rest of the pavement, and that the resistance to wear should be uniform throughout the life of the pavement. Notwithstanding these advantages, local conditions may sometimes justify the two-course type of construction. For example, if the only materials locally available for use as aggregate were of very inferior quality, it might be more economical to use them for aggregate in the lower course of a two-course pavement and import aggregate for the wearing course than to employ a one-course pavement and import all the aggregate. The two-course pavement also requires slightly less cement per square yard than the one-course type if different proportions are used in the top and bottom courses; but this factor alone would seldom, if ever, justify a preference for the former type, especially in view of the objections to this method of construction, already noted.

Besides the two general types of concrete pavement described above, there are several special patented types, but so far as is known these do not possess any particular advantages and will not be discussed in detail. The one-course pavement is believed to be better adapted to most ordinary conditions than any other type of concrete pavement and will be given principal consideration in the following discussion.

Plates I to IV are arranged in logical sequence, to show the various steps in the construction of a one-course concrete pavement and are intended to supplement the descriptions of construction methods given below.

GRADING AND PREPARING THE SUBGRADE.

In forming a roadbed upon which a concrete pavement is to be constructed, the features which should receive primary consideration are (1) adequate drainage, (2) firmness, and (3) uniformity in grade and cross section.

It is impracticable to prescribe definite methods for securing thorough drainage which would be applicable to every location. The local conditions which affect the accumulation and "run-off" of both surface and ground water vary considerably even in the same locality, and it is only by means of a careful study of these conditions that a satisfactory system of drainage can be devised. For example, if the material composing the roadbed consists of springy earth, either tile or French drains would probably be necessary. In another case extremely flat topography may make it necessary to elevate the grade, by means of an embankment, considerably above the level of the ad-

FIG. 1.—PREPARING SUBGRADE.

FIG. 2.—SAND AND GRAVEL PILED ON SUBGRADE READY FOR USE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

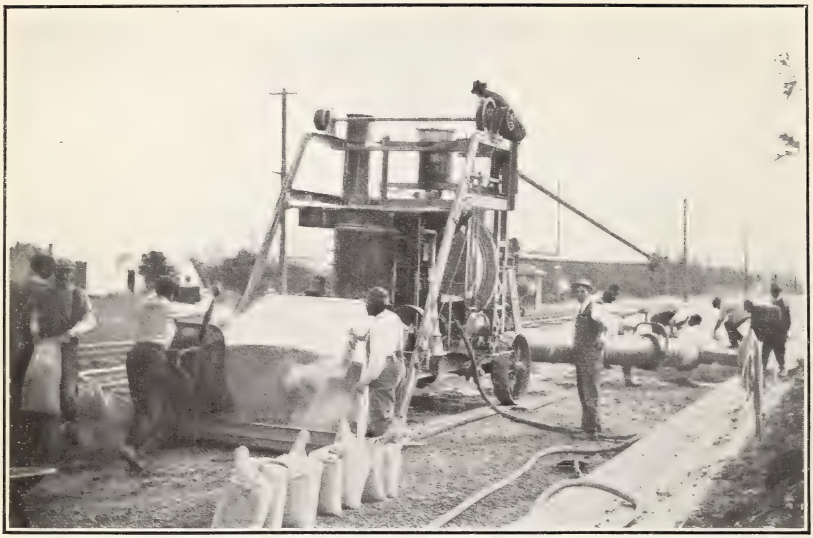

FIG. 1.—CHARGING CONCRETE MIXER.

FIG. 2.—PLACING CONCRETE AND USING TEMPLATE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

FIG. 1.—FINISHING THE SURFACE WITH A WOODEN FLOAT.

FIG. 2.—CANVAS COVERING IN PLACE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

FIG. 1.—COVERING THE SURFACE WITH A LAYER OF EARTH AFTER CANVAS IS REMOVED.

FIG. 2.—AFTER NEARLY TWO YEARS' SERVICE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

FIG. 1.—BITUMINOUS WEARING SURFACE IN FAIR CONDITION AFTER ABOUT ONE YEAR'S SERVICE.

FIG. 2.—SHOWING UNSATISFACTORY CONDITION OF BITUMINOUS WEARING SURFACE AFTER LESS THAN ONE YEAR'S SERVICE.

EXPERIMENTAL CONCRETE ROAD, CHEVY CHASE, MD.

FAILURE OF CONCRETE PAVEMENT CAUSED BY SETTLEMENT OF EMBANKMENT.

jacent land. The nature of the soil, the character of the topography, and the amount and rate of rainfall must all be taken into consideraation, if a system of drainage is to be properly planned.

The second requirement, firmness, can be secured only after the road has been properly drained. Soils which readily absorb moisture will not remain firm in wet weather and therefore should not be permitted to form a part of the roadbed, especially if they occur in the subgrade. This requirement also makes it necessary that the roadbed be thoroughly compacted. In forming embankments the material should be put down in layers not more than about 12 inches thick, and each layer should be thoroughly rolled. (See Pl. VI.) The subgrade in both excavation and embankment should be brought to its final shape by means of picks and shovels and rolling.

The cross section of the subgrade may be either flat or shaped to conform with the finished surface of the pavement. The flat cross section involves the use of a slight additional quantity of concrete, but gives an increased thickness at the center, where maximum strength is required. It has been observed that longitudinal cracks occur less frequently in concrete pavements laid on a flat subgrade than where the subgrade is curved to conform to the surface of a crowned pavement.

In either case the subgrade when completed should be uniform in grade, cross section, and firmness, not only to prevent a waste of concrete in filling up depressions but in order to facilitate the necessary movement of the pavement due to contraction and expansion and thus reduce its tendency to crack. The subgrade should be rolled and reshaped until the specified shape is secured. The forms, which should be set before the final shaping, may be made to serve as a guide for this work.

USE OF SUB-BASE.

Where old pavements which have been constructed on a sub-base are replaced by concrete pavements, it is frequently convenient to place the new pavements on the old sub-base. Furthermore, soil conditions are sometimes such as to make the use of a sub-base very desirable. This is especially true of soils which do not compact readily under the roller or which can not be effectively drained at a reasonable cost.

A satisfactory sub-base may be constructed of gravel, broken stone, telford, cinders, or any other similar material. The essential features in every case are firmness, smoothness, and uniformity in grade and cross section. Telford is seldom employed as a sub-base for concrete pavements, except when old macadam roads having such sub-bases are being repaved with concrete. When this is the case it would seem advisable to spread a layer of sand or other fine material over the sub-

base before the concrete is placed. Otherwise the irregularities in the telford surface would prevent the pavement from contracting and expanding readily and would thus cause cracks to occur at frequent intervals.

When old macadam or gravel roads are to be surfaced with concrete it is advisable to scarify the entire surface to a depth of several inches before the subgrade is shaped to receive the concrete. If this is not done, it is almost impossible to prevent a lack of uniformity in the subgrade wherever it is necessary to grade or shape up any part of the old road.

It has been suggested, with an apparent show of reason, that a thin cushion of sand might be advantageously used under concrete pavements. The purpose of this construction is to facilitate the sliding of the pavement, due to expansion and contraction, and thus to increase the allowable distance between contraction joints. So far as is known there are no experimental data which bear on this subject.

FORMS.

The form work required for concrete pavements is very simple and inexpensive. Ordinarily the forms may consist of 2½-inch boards having a width equal to the edge thickness of the pavement, though metal forms are in general more economical and are always to be preferred. The forms should be set before the subgrade is finished, in order to serve as a guide for the finish grading, and should be securely held in place by means of stakes driven on the shoulder side to such depth that they do not extend above the top of the forms. Care should be taken to see that the forms bear uniformly on the subgrade, as otherwise they are likely to sag while the concrete is being struck off and tamped, and thus produce an irregular surface. It is also well to have the ends of the different sections fastened together in such a manner that no relative displacement is possible.

The forms should always be set true to line and grade, and where curbs or gutters are to be provided they must be modified to suit the requirements for these features.

MIXING AND PLACING THE CONCRETE.

When a considerable area of concrete pavement is to be laid it is usually economical to employ a mechanical mixer for mixing the concrete (Pl. II, fig. 1). Hand mixing is much more expensive than machine mixing, and hand-mixed concrete is rarely as uniform as machine-mixed concrete either in consistency or in the distribution of the component materials. Since lack of uniformity is believed to be one of the most potent causes for the formation of cracks, machine mixing is greatly to be preferred. There are several makes

of machine mixers which have proved to be satisfactory for such work. The self-propelled batch type with a distributing device is probably the most economical to use where the amount of work to be done is sufficient to warrant the purchase of such a machine.

The distributing device may consist of a bucket and boom attachment or of a chute or a revolving tube which conveys the concrete from the drum of the mixer to its place in the road. The chute is objectionable, because if the concrete is mixed to such a consistency that it will readily flow down the chute it is too wet for best results; and, furthermore, there is a tendency for the mortar to separate from the coarse aggregate. This is especially true when the mixer is working down a steep grade. No matter what kind of distributing device is used, however, steep grades are liable to interfere with the proper working of the mixer, and if such grades occur on any particular piece of work that is to be undertaken this point should be investigated before the concrete mixer is purchased.

Even when the very best type of concrete mixer is employed it is necessary to exercise considerable care to see that the concrete is mixed thoroughly and to a uniform consistency. Tests have shown that increasing the time during which a batch of concrete remains in the revolving drum of a mixer, within reasonable limits, has very much the same effect as increasing the proportion of cement. It is also almost certain that varying amounts of water in successive batches will tend to cause cracks to develop in the pavement. It is impracticable to state definite rules for determining the number of turns of the mixer drum or the exact quantity of water which each batch should be given, because these features are considerably affected by the condition of the mixer and the materials. In general it may be said that each batch should be mixed until there are no uncoated particles of sand or coarse aggregate remaining, and the amount of water should be such that the resulting concrete will be quaky or jellylike, but not sufficiently wet to flow readily while it is being handled. On steep grades somewhat less water should be used in mixing the concrete than when the grade is level. A comparatively wet concrete is easier to handle on level grades, but is liable to flow on steep grades after the pavement has been struck off and tamped, causing irregularities to develop in the surface.

Immediately after the concrete is mixed it should be deposited in the pavement. Otherwise the materials of which it is composed will begin to separate, and if it is permitted to stand an appreciable length of time before being placed the heavy materials will settle to the bottom of the containing vessel, so that when it is emptied a core will be formed in the center of the space occupied by the batch. Concrete mixed in a stationary mixer and hauled to its place in the road is especially subject to this objection.

Before any concrete is placed the subgrade should be thoroughly sprinkled with water or a part of the water contained in the concrete will be absorbed by the subgrade, which may interfere with the process of setting.

For one-course work the concrete should be deposited between the forms in such quantity that when it is struck off and compacted it will present a uniform surface and have the depth required for the finished pavement. Each batch of concrete should be dumped as nearly in place as is practicable and should preferably be spread by means of mortar hoes. The men who do the spreading should avoid walking in the concrete, because each time the foot sinks into it the coarse aggregate is shoved down, and when the foot is withdrawn the space thus left tends to fill with mortar, which causes a lack of uniformity in the concrete.

After the concrete has been spread approximately to the required cross section it should be struck off with a strike board having slightly more crown than the cross section of the road. This allows for a slight amount of settlement when the concrete is compacted. The compacting should be done with a tamper shaped to conform with the cross section of the road and operated by two men, one standing on each side of the pavement. Suitable designs for strike boards are shown in Plate X, figures 2 and 3. The heavier design (Pl. X, fig. 3), on account of its durability, is especially adapted for use where a considerable amount of work is to be done. It is also in general somewhat more satisfactory than the light design on account of its greater rigidity. Plate X, figure 4 shows a design for a tamper made of steel which has been used very satisfactorily for compacting concrete after it has been struck off, and which is very rigid and durable.

Sometimes the tamping and striking off are done with the same template, but this is not altogether satisfactory, because when this is done it is impracticable for the template to have a greater crown than is required for the finished pavement, and it is difficult to strike off the concrete with such a template and at the same time make provision for compacting.

In the case of two-course pavements it is important that the top course be placed before the concrete in the bottom course has taken its initial set. The bottom course should be well compacted and struck off, but the striking off need not be as carefully done as in the case of the top course. The top course should be constructed in a manner similar to that described for one-course pavements.

FINISHING THE SURFACE.

The surface of a concrete pavement may be given either a rough or a smooth finish. A slightly roughened surface has the advantage of

being less slippery when the pavement is first constructed and is preferred by some engineers on that account. Smooth surfaces are more generally preferred, except on very steep grades, where it is sometimes desirable to provide grooves or other comparatively deep markings at right angles to the direction of traffic in order to afford a better foothold for horses. Such grooves, however, will cause rapid deterioration of the pavement under heavy traffic.

A satisfactory method of finishing the surface is to use a wooden float for smoothing out all template markings (Pl. III, fig. 1) and evening up other slight irregularities. This method of finishing produces a surface sufficiently rough for all ordinary grades and possesses the advantage of being extremely simple. In using the float special care must be exercised to keep the pressure of the hand uniform, in order not to produce irregularities in the surface. Wherever a depression occurs it should be filled by adding concrete, and not by raking mortar into it with the float. The workmen who do the floating should be provided with one or more light bridges, which span the pavement and which can be easily moved as the work progresses. Various sizes of floats are used, and provided they are handled by skilled workmen the size is not important. The long float shown in Plate X, figure 5, requires less skill on the part of the operators than short floats. A suitable design for a finishing bridge is shown in Plate XI, figure 1.

JOINTS.

It is customary to provide transverse joints at regular intervals in concrete pavements, to prevent irregular cracks from being produced; and if the width of the pavement exceeds 20 feet, longitudinal joints are also usually provided. Concrete contracts and expands with changes in temperature and also with changes in its moisture content. It also shrinks or contracts upon setting; and since the strength of the concrete is then comparatively low, the tensile stresses developed are much more likely to produce cracks than equivalent stresses developed in older concrete. It is evident that the greatest longitudinal stress which can be developed at any section of the pavement, due to contraction, is equal to the weight of the pavement, included between the section under consideration and the nearest free end, multiplied by the coefficient of friction between the pavement and the subgrade. Therefore, if contraction joints are spaced sufficiently close together to prevent this stress from exceeding the tensile strength of the concrete, no cracks should occur.

If no transverse joints are constructed in the pavement, the length of the sections between cracks, judging from such limited data as are at present available, will vary from 20 to 150 feet, and depends upon the kind of aggregate used, the relative richness of the concrete, the

condition of the subgrade at the time the concrete is placed upon it, and the method employed in curing the concrete. It is common practice to space the transverse joints from 25 to 50 feet.

If there were no curves in the alignment, or summits in the grade of a road, it is doubtful if any provision for expansion would be necessary in constructing the joints, because the elasticity of the concrete should be sufficient to take care of the expansion caused by changes in temperature and moisture content. In nearly all cases, however, there are curves in alignment and changes in grade which might permit a displacement of the pavement before a very high compressive stress was developed. For this reason it is advisable that joints be constructed to provide for a slight amount of expansion as well as for contraction.

There are a number of different methods of constructing joints, but none of them appear to be entirely satisfactory from every standpoint. Probably the simplest type of joint is that made by introducing into the pavement a board about five-eighths inch thick and shaped to conform with the cross section. This board is held in place by means of stakes until the concrete is placed against it on both sides. The stakes are then removed and the board is left in place with its upper edge even with the surface of the pavement and its lower edge resting upon the subgrade. The principal objections to this joint are that the board wears rather rapidly and does not protect the adjacent edges of the concrete.

A second method is to form a plane of weakness by placing a board so that its top edge is about 3 inches below the surface of the pavement. Then, when the contraction of the concrete has caused a crack to form immediately over the board, the crack is filled with bituminous material. This joint is said to have proved very satisfactory for dense concrete where the distance between joints is comparatively small, but it is subject to the objection that compressive stresses developed by expansion of the concrete are likely to be concentrated in the upper part of the pavement and to cause spalling at the joints.

Another method is to use a board, such as that first described, which is removed before the concrete has taken its final set. The opening thus left is later filled with bituminous material. The principal difficulty with this method is that when the board is withdrawn the adjacent edges of the concrete are usually disturbed and a rough joint is produced.

Probably the method most often used in constructing joints is to separate the successive sections of the pavement by means of specially prepared bituminous felt boards. These are usually held in place by means of properly shaped steel templates until the concrete is deposited against them, after which the templates are removed and the concrete flows around the boards. The thickness of this

joint has varied in common practice from one thickness of two-ply tar paper up to about one-half inch. A thickness of one-quarter inch seems to give very satisfactory results when the joints are spaced about 30 feet apart. Joints of this kind are sometimes provided with metal armor, which is intended to keep the adjacent edges of the concrete from being spalled off. It is claimed that armored joints require less maintenance than other types, but they are more expensive to construct.

The joints are undoubtedly the weakest feature of the concrete pavement; and no matter what type of joint is used, they must be given frequent and careful attention to prevent rapid deterioration of the pavement adjacent to them.

In the past, contraction joints of all types have usually been placed at right angles to the line of the pavement. This method of construction has the disadvantage that two wheels of a vehicle strike the joint at the same time and thus produce the maximum amount of impact. By skewing the joint at an angle of about 15 degrees the wheels strike one at a time, and the total resultant impact is reduced by at least one-half. This is advantageous to both the traffic and the pavement, and since the difficulties involved in constructing skewed joints are not at all serious, there is no apparent objection to their use.

PROTECTING AND CURING THE CONCRETE.

The quality of the concrete depends to a great extent upon the conditions under which it sets or hardens. When early exposed to dry air, for example, water is evaporated out, thereby greatly accelerating the shrinkage of the concrete and delaying the process of setting. It is evident that these results form a very effective combination for producing cracks. The effect of freezing on concrete is still more harmful; not only are cracks produced, but the internal structure of the concrete is also damaged.

The precautions that must be taken in order to protect a newly constructed concrete pavement during the process of curing depend largely on the weather conditions. In drying weather small hair-like cracks will frequently begin to form almost as soon as the surface of the concrete is finished, and unless the concrete is quickly covered and protected from the air these cracks increase in size very rapidly. At other times, when the atmosphere is moist, the concrete may sometimes be permitted to stand for several hours before being covered, without any danger of cracks forming. Heavy canvas made into sections of convenient length and proper width should be used for covering the concrete surface (Pl. III, fig. 2). The canvas should be spread over the pavement as soon as this can be done without marring the surface. Under unfavorable

atmospheric conditions it is sometimes better to spread the canvas immediately after the surface is finished, even at the risk of marring the surface slightly, than to run the risk of having cracks develop in the pavement. The canvas should be sprinkled until thoroughly wet immediately after it is spread and should be kept wet until removed and replaced with an earth covering. Under ordinary weather conditions about 24 hours will be required for the concrete to set sufficiently hard not to be damaged by men walking upon it while covering it with earth. The canvas should therefore usually remain on the pavement about one full day. Immediately after the canvas is removed the pavement should be covered with a layer of earth about 2 inches thick, which should remain on the pavement and be kept constantly wet for a period of about two weeks. During this period the roadway should be kept entirely closed to traffic. If the weather conditions are favorable the concrete ought to be sufficiently strong to withstand traffic at the end of two weeks. In cold or otherwise unfavorable weather the earth covering should preferably be thicker than 2 inches and left in place for a longer period of time. No concrete should be laid during freezing weather, but if danger of freezing develops after the concrete is laid and before it sets, the first cover of canvas should be supplemented in some way in order to prevent damage to the pavement. This may be done by spreading over it a layer of straw, or by using two thicknesses of the canvas, if this is practicable.

The protection of the concrete is an extremely important feature of concrete-pavement construction. It is impossible to secure satisfactory results unless some such precautions as those described above are taken to prevent the concrete from drying out too rapidly after it is placed, and to insure that it sets up under uniformly favorable conditions.

THE USE OF REINFORCING STEEL.

Probably the most satisfactory method, in point of efficiency, yet devised for reducing the number of objectionable cracks in concrete pavements is that of employing steel reinforcement. The reinforcement usually consists of woven wire or some similar material, though there is no apparent reason why plain round or square rods might not be satisfactorily used. One-quarter-inch round rods embedded about 2 inches above the lower surface of the pavement and spaced about 12 inches center to center in both directions would seem sufficient to eliminate practically all objectionable cracking, provided proper joints were introduced at changes in the grade and at curves in the alignment. But any satisfactory system of reinforcement will probably add from 15 to 20 cents per square yard to the cost of the pavement, and this additional cost is no doubt responsible for the

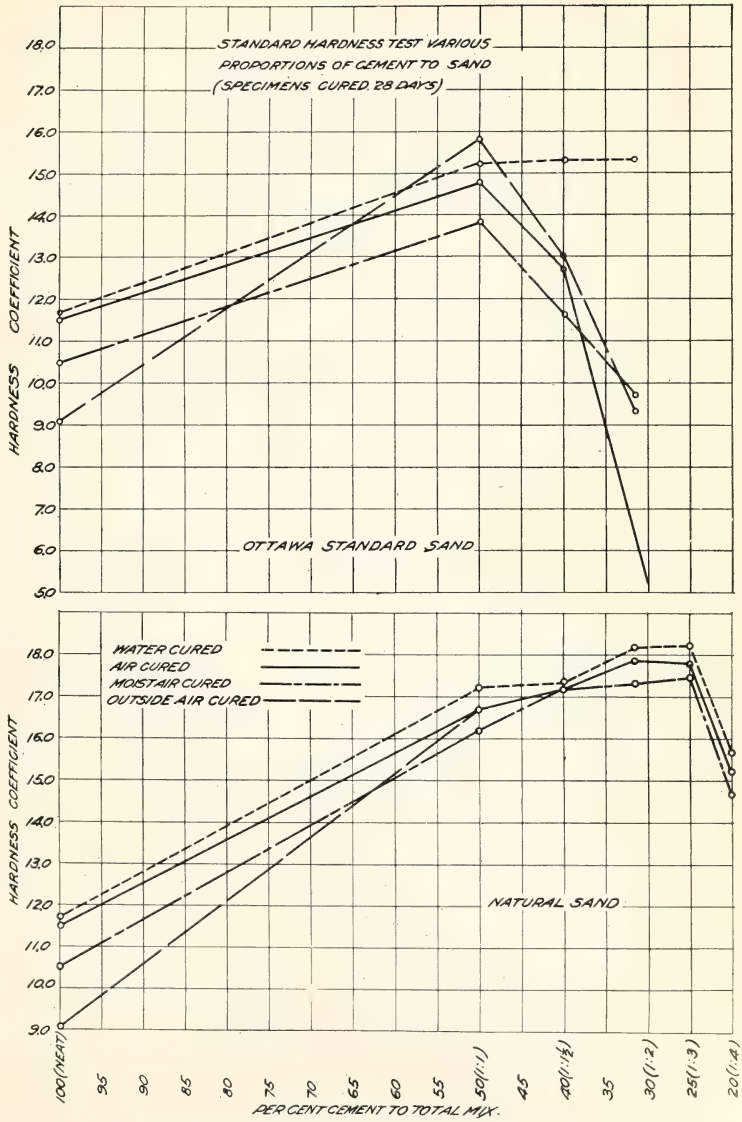

DIAGRAM SHOWING RESULTS OF HARDNESS TESTS OF CEMENT MORTARS.

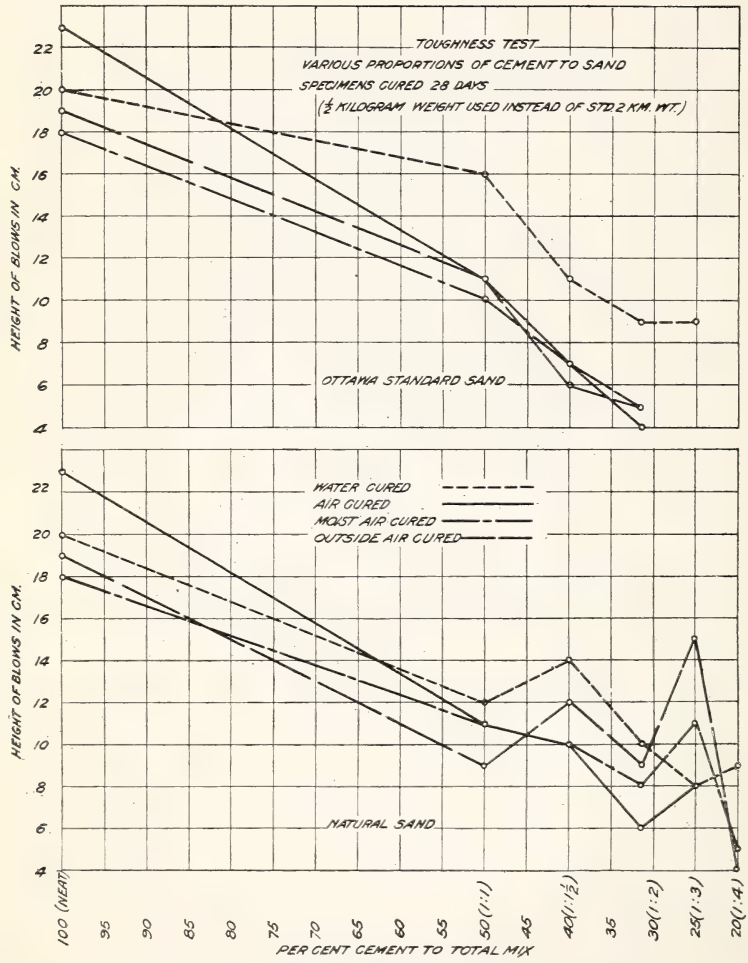

DIAGRAM SHOWING RESULTS OF TOUGHNESS TESTS OF CEMENT MORTARS.

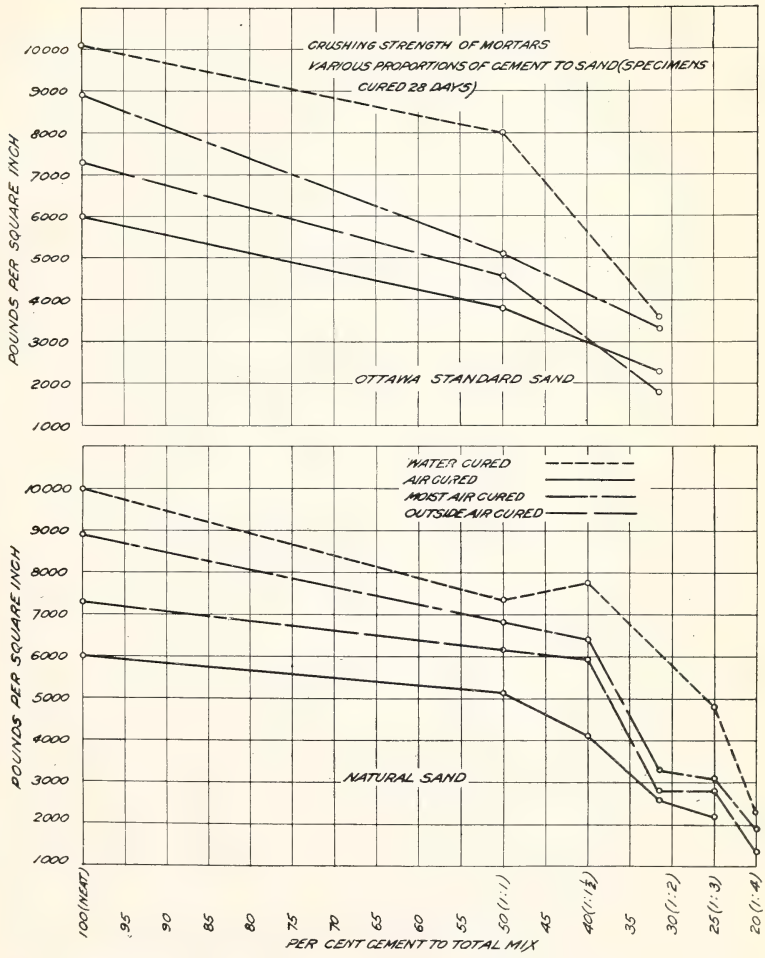

DIAGRAM SHOWING RESULTS OF CRUSHING STRENGTH TESTS OF CEMENT MORTARS.

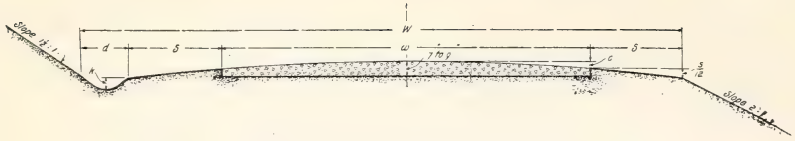

FIG. 1.—TYPICAL SECTION OF CONCRETE ROADWAY.

Side ditches should be of sufficient size to dispose of all drainage; C may vary from $\frac{W}{96}$ to $\frac{W}{72}$; when w exceeds 20 feet make joint in center and crown subgrade; k varies from 6 to 12 inches.

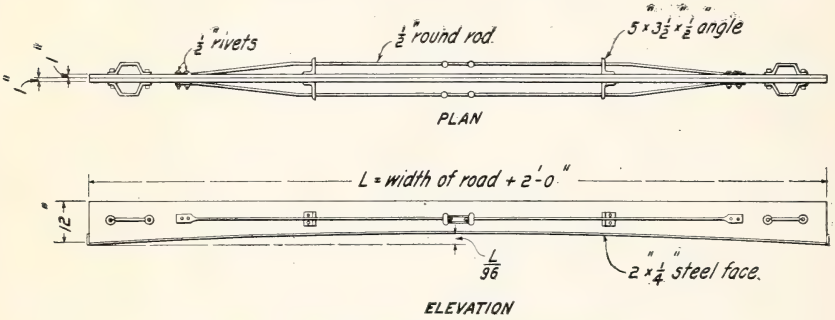

FIG. 2.—TYPICAL DESIGN FOR STRIKE BOARD.

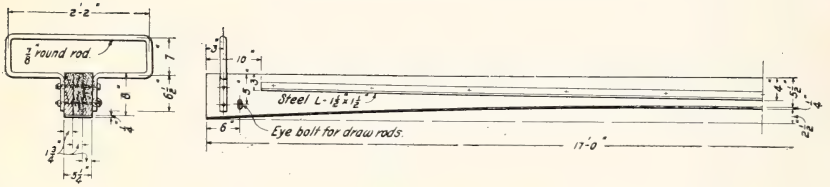

FIG. 3.—WOODEN STRIKE BOARD.

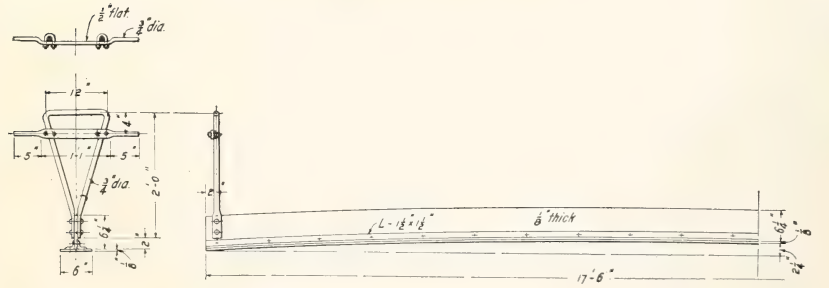

FIG. 4.—STEEL TAMPER.

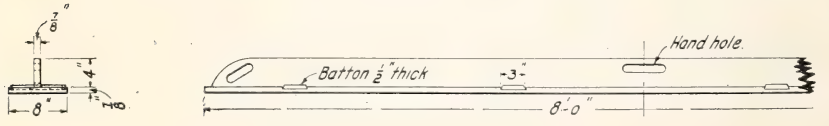

FIG. 5.—LONG WOODEN FLOAT.

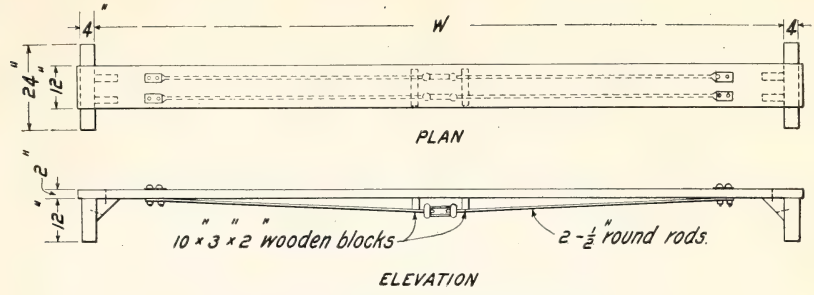

FIG. 1.—TYPICAL DESIGN FOR FINISHER'S BRIDGE.

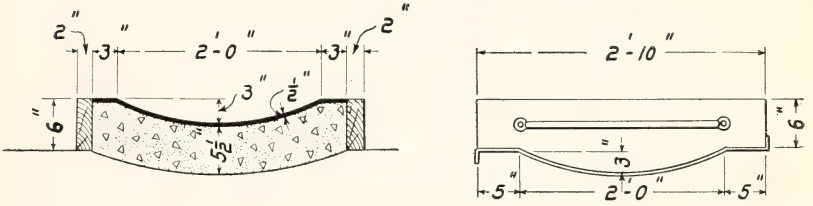

FIG. 2.—TYPICAL CROSS SECTION OF CONCRETE GUTTER AND DESIGN FOR A TEMPLATE TO BE USED IN ITS CONSTRUCTION.

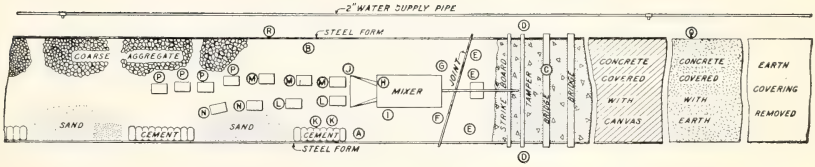

FIG. 3.—DIAGRAM SHOWING DISTRIBUTION OF FORCE, USING 2-BAG MIXER.

A, foreman; B, subforeman; C, finisher; D, 2 laborers striking and tamping; E, 3 laborers placing concrete and assisting in striking; F, mixer tender; G, laborer cleaning subgrade and setting joints; H, mixer engineer; I, fireman, also sprinkles subgrade; J, laborer assisting wheelers and cement handlers; K, 2 laborers handling cement; L, 2 laborers wheeling sand; M, 3 laborers wheeling coarse aggregate; N, 2 laborers loading sand; P, 4 laborers loading coarse aggregate; Q, laborer sprinkling pavement; R, water boy. Total, 2 foremen and 25 laborers. ▭ indicates wheelbarrow.

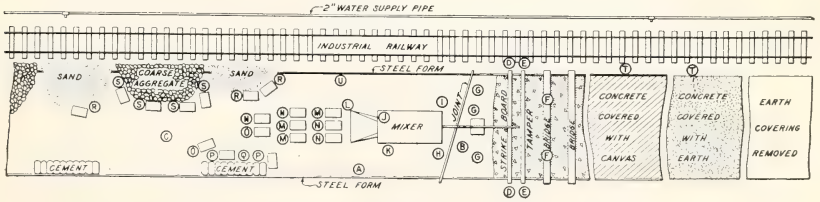

FIG. 4.—DIAGRAM SHOWING DISTRIBUTION OF FORCE, USING 3-BAG MIXER.

A, foreman; B, subforeman on placing concrete; C, subforeman on charging mixer; D, 2 laborers striking; E, 2 laborers tamping; F, 2 finishers; G, 3 laborers placing concrete; H, mixer tender; I, laborer cleaning subgrade and setting joints; J, mixer engineer; K, fireman, also sprinkles subgrade; L, laborer assisting wheelers; M, 3 laborers wheeling sand; N, 4 laborers wheeling coarse aggregate; O, 2 laborers wheeling cement; P, 2 laborers handling cement; Q, laborer opening bags; R, 3 laborers loading sand; S, 4 laborers loading coarse aggregate; T, 2 laborers sprinkling pavement; U, water boy. Total, 3 foremen and 36 laborers. ▭ indicates wheelbarrow.

fact that concrete pavements are seldom reinforced. Furthermore, reinforced pavements are more difficult to repair than those made of plain concrete, which may be a very serious objection under some circumstances.

GUTTERS.

It is frequently desirable to provide concrete pavements with paved gutters in order to prevent the side ditches from eroding. Plate XI, figure 2, shows a typical design for a concrete gutter. This design has been frequently used and has usually proved to be satisfactory. A suitable strike board for forming this gutter is also shown in the figure.

It is impracticable to construct the pavement and the gutter at the same time, and on account of the convenience of using the pavement as a platform for material and for mixing concrete for the gutter the pavement is usually constructed first. When there is no space between the gutter and pavement the joints should always be continued through both. If this is not done, the joints in each are apt to be continued as cracks in the other.

CURBS.

Concrete pavements on country roads are not generally provided with curbs, because it is usually desirable to use the shoulders as part of the roadway. Under some circumstances, however, curbs may be employed to advantage. For example, in deep cuts it might be justifiable economy to omit the shoulders and side ditches and provide curbs along the edges of the pavement so that the sides of the pavement would serve as gutters. Likewise, on very deep fills curbs are sometimes used to protect slopes from erosion. When this is done it is necessary to provide catch basins at low points in the grade.

BITUMINOUS WEARING SURFACE.

Since 1906 a number of experiments have been made in an effort to develop some satisfactory method of constructing a bituminous wearing surface on concrete pavements. Various kinds of bituminous materials have been used and several methods of applying them have been tried. Some of the surfaces are reported to have given moderately good service under light traffic, but in general they have not been durable where the traffic is at all heavy. The uneven manner in which they fail tends to produce excessive wear on portions of the concrete, and renewals should be made promptly as needed.

The principal advantages claimed for bituminous wearing surfaces on concrete pavements are:

(1) They make it possible to substitute continuous maintenance for periodic renewals of the pavement.

(2) They reduce the noise made by the impact of horses' hoofs and steel-tired wheels.

(3) They remove the principal objection to bituminous expansion and contraction joints.

(4) They overcome the somewhat objectionable glare of concrete pavements in strong light, though this objection may also be overcome with much less cost by sprinkling the pavement with crude water-gas tar.

The principal disadvantages may be inferred from what has already been said. It is also well to note that, where traffic conditions are such as to make a bituminous surface practicable on a concrete road, a bituminous-surfaced macadam road might also be practicable and would certainly be cheaper to construct, unless the difficulties involved in securing suitable stone for the macadam were very unusual.

In constructing bituminous surfaces on concrete it is essential to have the surface of the concrete entirely clean and free from laitance when the bitumen is spread. Generally about one-half gallon of bitumen to the square yard is put on in either one or two applications, by hand or by means of pressure distributors. It is sometimes swept with hand brooms in order to make it adhere better to the pavement. Hot applications have hitherto been almost exclusively used, though there is no apparent reason why materials which could be spread cold might not be employed with equally satisfactory results.

After the bitumen has been spread as described, it is covered with coarse sand, pea gravel, or stone chips, applied at the rate of 1 cubic yard to from 75 to 100 square yards of surface. The road may be opened to traffic almost immediately after the sand or stone chips are spread. Plate V shows the conditions of different concrete roads with bituminous wearing surfaces after certain periods of service.

It is realized that the above discussion of bituminous wearing surfaces falls very far short of furnishing a guide for undertaking work of that kind. The available data upon this subject, however, are not considered sufficient to form a basis for a more comprehensive discussion. Not only have contradictory results been reported by different engineers concerning the same methods of construction, but the results now being obtained from carefully conducted experiments by the Office of Public Roads with different materials and different construction methods do not yet seem to warrant any definite statements as to what materials are best adapted for such work nor which construction method will give the best results, though they do indicate in a general way that tars are preferable to asphalts for this purpose.

METHODS, ORGANIZATION, AND EQUIPMENT.

When it is considered that ordinarily from one-third to one-half of the total cost of constructing a concrete pavement is for the labor employed in doing the work after the materials are delivered, the importance of efficient organization, proper equipment, and economical methods becomes readily apparent. Failure to give these features proper consideration may easily result in adding from 10 to 20 per cent to the cost of a concrete pavement, and has no doubt frequently caused road contractors to sustain a net loss on projects of this kind, where profits might have been made.

It is not the province of this bulletin to furnish detailed rules for the guidance of contractors in planning and executing their work, but it seems desirable to discuss briefly a few important points which contractors and engineers in charge of force-account work should consider in connection with concrete-pavement construction. The points which are of most importance, and to which the discussion will be confined, are concerned with, first, the proper order and progress of the work; second, the economic handling of materials; and third, the amount of capital necessary to carry on such work economically.

ORDER AND PROGRESS OF THE WORK.

In constructing a concrete pavement it is especially desirable that the work of mixing and placing the concrete be as nearly continuous as practicable after it is once begun. Where the mixer is permitted to stand idle for even a few days the force of laborers employed in operating it will usually become more or less disorganized, and an appreciable amount of loss and unsatisfactory work will generally result when the mixing is resumed. On this account the order and progress of the work should ordinarily be planned with the primary view to keeping the mixer going full time every working day that the weather will permit. This means that ample provision should be made for completing the drainage structures, the grading, and the preparation of the subgrade well ahead of the mixer, as well as for supplying the mixer with all necessary materials.

The drainage structures should preferably be completed in advance of the grading in order to obviate the necessity for moving embankment material the second time. Where the concrete materials are to be hauled out by means of an industrial railway, however, it is usually impracticable to extend the railway ahead of the grading, and the saving effected in hauling the materials for the drainage structures on the industrial railway may justify permitting the grading to proceed ahead of the drainage structures.

Rather than construct a concrete culvert sufficiently far in advance for the subgrade to be prepared before the mixer arrives, it may sometimes be economical to leave out a section of the pavement over the culvert. But the extra expense involved in going back and putting in a section of this kind after the work of laying the pavement has progressed a considerable distance ahead is usually considerable and is often underestimated by contractors. This method of doing the work also involves a delay in opening the road, and as a rule is very objectionable on that account.

The work of preparing the subgrade and setting the forms should preferably proceed sufficiently far in advance of the mixer to allow for two or three days' run. The prepared subgrade, if properly drained, dries out much more rapidly after rains than the rough grade, and thus it is possible to resume the placing of concrete much earlier than when the roadbed has not been shaped and rolled. A soaking rain will usually cause the prepared subgrade to heave slightly and make rerolling necessary, but ordinarily this is a very small item.

OPERATING THE CONCRETE MIXER.

In general it is economical to employ a mixer of the street-paving type for mixing and placing the concrete, though in some cases it has proved satisfactory to do the mixing in stationary mixers and haul the concrete out to its place in the road. This latter method is applicable to relatively only a very few sets of conditions, however, and will therefore not be discussed in detail.

There are two sizes of street-paving mixers commonly used in concrete road construction. The smaller is capable of mixing a batch, of the proportions usually required, containing two bags of cement, and the larger will mix a batch containing three bags of cement. The larger size is economical where materials can be rapidly obtained and where the amount of work to be done is sufficient to warrant providing equipment for handling the materials necessary to keep the larger mixer running up to its capacity. Where the materials can be economically obtained only at a slow rate, or where the expense of providing facilities for handling large quantities of materials would be excessive, the smaller size of mixer is more economical to use. When efficiently operated, either size of mixer should ordinarily mix from 400 to 450 batches of concrete in a working day.

Organizing a force of laborers to operate a paving mixer efficiently requires considerable skill in handling men. The best results are generally obtained when a mixer is fully manned and each laborer is assigned definite work to perform.

The accompanying diagrams, Plate XI, figures 3 and 4, illustrate mixer organizations for the two sizes of mixers in general use, which

were worked out by a contractor of considerable experience. Laborers for preparing the subgrade, setting the forms, and for covering the concrete with earth should be provided in addition to those called for in the diagrams.

HANDLING MATERIALS.

One of the most difficult problems which has to be solved in connection with concrete road construction is that of determining the proper methods to employ in handling and delivering the materials for the concrete. The different kinds of material required must be delivered to the mixer in definite proportions at the same time, and it is evident that the location of the several sources from which the materials are obtained, with respect to each other and to the road, will have a very great influence in determining the most economical transportation methods.

Consider, for example, a project on which is used a concrete mixer of the street-paving type which mixes a batch containing three sacks of cement. If the work is to progress normally, the quantities of the different materials required each day will be approximately as follows:

Cement	barrels	320
Sand	cubic yards	70
Coarse aggregate	do	140
Water	gallons	8,800

In addition to the above, if the mixer runs continuously, about 10,000 gallons of water will be required each day for keeping wet that part of the pavement which will have been laid during the two preceding weeks, and for sprinkling the subgrade before the concrete is placed. This makes the total weight of water which may be required each day about 75 tons, and the total weight of all the materials combined about 420 tons per day.

The importance of the water supply is not always appreciated by contractors and engineers, and the provision made for delivering water on the work has sometimes been entirely inadequate. Another frequent error is that of overestimating the amount of water which a chosen stream is capable of supplying. In general, the most practicable method of delivering the water is to pump it through a pipe line laid along the road. The pipe should be at least 2 inches in diameter, and for the mixer under consideration the pump should be capable of furnishing about 25,000 gallons of water in 10 hours to any point on the pipe line. Ordinarily at least 10,000 feet of pipe will be required if the concrete is to be sprinkled for two weeks after it is laid.

The proper method of handling the cement is sometimes considerably affected by the requirements which the specifications provide regarding tests. Some specifications require that the cement shall be held until the results of the 28-day test are reported, while others permit its use as soon as it has satisfactorily passed such tests as may be made within seven days. If any tests of consequence are required and the sampling is not done until the cement arrives at the nearest railroad station, it will be necessary either to unload and store it or pay demurrage charges. This difficulty may be overcome to some extent by placing an inspector at the cement plant to collect and forward samples to the testing laboratory as soon as the cars are loaded. The testing may then be begun while the cars are en route.

Another plan sometimes employed to lessen the demurrage and avoid rehandling is to purchase bin-tested cement and have the cars loaded under the supervision of an inspector. When this is done, the cement may be used as soon as it arrives on the work, but the custom of cement manufacturers to make a slight additional charge for bin-tested cement may entirely offset the economical advantages gained by its use.

No matter what the arrangements for testing the cement may be, provision should usually be made for storing near the work sufficient cement to keep the mixer going for four or five days, in case that shipments are delayed, as frequently happens.

In general, the most satisfactory method of hauling the materials for the concrete is by means of an industrial railway constructed along one shoulder of the road, though this method is not always the most economical. Teams, traction engines with trailers, and motor trucks with or without trailers have each been frequently used for this purpose, and are no doubt each economically best adapted to certain sets of conditions. But all of these are objectionable from a construction standpoint on account of the damage which they usually do to the subgrade.

Among the advantages possessed by an industrial railway for hauling the concrete materials are:

(1) Materials may be delivered without disturbing the subgrade.

(2) The railway may be readily operated along the shoulder of a newly laid pavement, which makes it practicable to prosecute the work at any desired point.

(3) Hauling is affected comparatively little by weather conditions.

(4) Where there is sufficient work to keep an industrial railway outfit busy, it is usually economical, especially where the size of the projects is such that the railway can be operated continuously throughout a season on the same project. The purchase of an industrial railway outfit, however, usually involves a greater outlay of capital than is desirable for a single project.

From a purely economical standpoint the choice of means for hauling the materials would probably be made about as follows:

First. Where the maximum haul does not exceed 3 miles and the amount of concrete to be laid does not exceed about 5,000 cubic yards, team haul would probably be economical.

Second. If the amount of concrete to be laid exceeds about 5,000 cubic yards, or if the maximum haul exceeds about 3 miles, and the materials are hauled in from the same direction, an industrial railway, tractors, or motor trucks may be economically used.

Third. Where the materials are hauled in from each end of the road, or where it is desired to operate more than one mixer at the same time, the industrial railway is usually more practical and economical.

Where the sand and coarse aggregate are shipped in by rail, the work of unloading the railroad cars and loading the wagons or cars in which the materials are to be hauled out to the work can usually be most economically done by means of machinery especially adapted to this kind of work. In order to avoid paying demurrage, and to have the materials on hand when they are needed, it is nearly always necessary to handle a considerable part of the materials the second time. Hence it may be desirable to have two sets of unloading and loading machinery in cases where the stock piles and bins are located out on the work instead of at the siding where the materials are delivered.

The kind of unloading and loading device to employ depends to a very great extent on the quantities of materials to be handled and the other conditions to be met. If the stock piles and bins are adjacent to the siding where the materials are delivered, and a considerable quantity of work is to be done, a locomotive crane may frequently be used to advantage, while, if the stock piles and bins are out on the work, it may be economical to handle the material at the siding with scrapers or similar devices and install an elevating device at the bins where the materials are stored. In other cases the extent of the work may not be sufficient to warrant any machinery whatever for handling the materials, in which event the handling may be rather expensive.

CAPITAL REQUIRED.

The amount of capital required to carry on concrete road construction successfully depends almost wholly on the size of the project and the circumstances under which the work is to be done. Where a considerable quantity of work is to be done in the same community it may be possible to keep a very elaborate equipment busy, even though the individual projects are comparatively small. On the other hand, it may be poor economy to provide more than the smallest practicable

equipment for a rather large project in a community where few other concrete roads are likely to be constructed.

The equipment necessary for handling and hauling the materials frequently represents a much greater outlay of capital than all other expenditures combined, but, as has already been pointed out in discussing the handling of materials, the conditions affecting this feature of the work are subject to great variation. A general discussion as to the cost of this part of the equipment, therefore, would usually be of small value in connection with any particular project and will not be undertaken.

The equipment necessary for doing the rough grading in connection with concrete road work is not essentially different from that required for grading other types of roads. Since the amount of capital necessary to provide grading equipment to suit various sets of conditions is familiar knowledge to practically all road engineers and contractors, this feature will not be discussed here.

The capital required to provide equipment for preparing the subgrade and mixing and placing the concrete depends on the rate at which it is purposed to carry on the work. The lists given below show the approximate cost of outfits using either a 2-bag or a 3-bag mixer.

Outfit No. 1 (2-bag mixer).

1 rooter plow	$50
1 road grader	300
1 heavy 4-horse plow	30
Shovels, picks, and other small tools	75
1 10-ton macadam-type road roller	2,500
1,800 feet of steel forms, complete with stakes, etc	200
1 pump and engine capable of delivering at least 1,500 gallons of water per hour	175
10,000 feet of 2-inch wrought-iron water pipe, with valves every 200 feet	950
400 feet of rubber hose, with couplings	80
12 wheelbarrows	60
1 concrete mixer, with skip and distributing device	1,600
Strike board, tamper, mortar hoes, sledges, etc	100
Total	6,120

Outfit No. 2 (3-bag mixer).

1 rooter plow	$50
1 road grader	300
1 heavy 4-horse plow	30
Shovels, picks, and other small tools	100
1 10-ton macadam-type road roller	2,500
3,000 feet of steel forms, complete with stakes, etc	325
1 pump and engine capable of delivering at least 2,500 gallons of water per hour	300
10,000 feet of 2-inch wrought-iron water pipe, with valves every 200 feet	950

600 feet of rubber hose, with couplings	$120
20 wheelbarrows	100
1 concrete mixer, with skip and distributing device	2,000
Strike board, tamper, mortar hoes, sledges, etc	100
Total	6,875

Ordinarily the method of paying for the work should enable the contractor to meet most of his bills for labor and materials after the first one or two estimates, so that the total amount of capital required for carrying on the work need not greatly exceed the cost of the equipment. For the average small project, where no very elaborate equipment is required to handle the materials, it seems that a total working capital of about $10,000 should be sufficient.

COST OF CONCRETE PAVEMENTS.

The cost of concrete pavements is almost wholly dependent on local conditions, and the conditions are seldom exactly the same, even for two projects in the same locality. It is therefore evident that a tabulation of cost figures for projects which have already been completed would be of little service in estimating the cost of new work, unless the conditions which affected the cost of the completed work could be fully compared with those under which the proposed work is to be done. Furthermore, some of the conditions which affect the cost of work are extremely uncertain. Among these are the weather, the efficiency of labor, and what is commonly called the element of luck. These may all influence the cost of a project to a considerable extent, but their influence can seldom be expressed in definite figures.

The most satisfactory method of arriving at the probable cost of a proposed pavement is first to ascertain by careful measurements and computations the quantities of the materials to be used and the various kinds of work to be done. An itemized estimate based on these quantities and the unit costs which prevail in the community for such materials and work may then be made. To this estimate should ordinarily be added a reasonable amount to cover unforeseen contingencies, and, also, if the work is to be done by contract, a fair profit for the contractor. From 15 to 20 per cent of the estimated cost is usually considered sufficient to cover these items.

In order to appreciate the importance of considering the different items separately in preparing an estimate of cost, it is necessary only to consider briefly the great amount of variation in unit costs.

The grading is usually paid for by the cubic yard of excavation, and the cost varies not only with the quantity but is greatly influenced by the character of the soil. In light, easily loosened soils grading may usually be done at from 25 to 40 cents per cubic yard. In hard earth containing more or less loose rock the cost per cubic yard gen-

erally varies from 40 to 75 cents, while grading in solid rock may sometimes cost as much as $1.50 per cubic yard. It is well to consider the cost of the rough grading entirely apart from the cost of the pavement. The drainage structures, however, may be considered together with the grading. The cost of these varies over such a wide range that no attempt will be made to discuss them here.

The cost of shaping and rolling the subgrade after the rough grading is completed is generally from 5 to 10 cents per square yard. This cost should be included with the other items which make up the cost of the pavement proper.

The cost of the concrete depends largely on the cost of the materials of which it is composed. These materials, delivered on the work, vary in cost according to the location of the work and the freight rates about as follows: Cement, from $1 to $2.50 per barrel; sand, from $0.60 to $2 per cubic yard; and broken stone or gravel, from $0.60 to $2 per cubic yard. The cost of mixing, placing, and finishing the concrete ordinarily varies from $0.60 to $1.25 per cubic yard, and depends on the efficiency of the organization and on whether the mixing is done by hand or machine. For machine mixing and labor at $0.20 per hour, $0.80 appears to be a fair average cost per cubic yard, including all overhead and incidental charges. The cost of constructing forms, contraction joints, etc., including the materials, is usually from $0.03 to $0.10 per square yard. Where simple types of joints and forms are used this cost should not exceed about $0.05 per square yard of pavement.

The following actual cost records taken from the 1912 annual reports of the Illinois State Highway Commission should prove helpful in estimating the cost of new work. These records do not appear to include any charges for the use of tools and machinery, but such charges should properly be included in preparing an estimate.

TABLE II.—*Cost of concrete roads in Illinois.*

Labor and supplies.	Project No. 1.		Project No. 2.		Project No. 3.	
	Totals.	Per square yard.	Totals.	Per square yard.	Totals.	Per square yard.
Superintendence	$140.00	$0.028	$157.50	$0.0220	$202.00	$0.0361
Shaping subgrade	307.41	.061	108.70	.0153	232.44	.0415
Loading and hauling sand and stone	267.34	.053	795.05	.1120	603.50	.1078
Mixing and placing concrete	414.63	.083	700.58	.0986	644.25	.1150
Watchman and miscellaneous labor	110.26	.022	131.46	.0184	383.75	.0686
Cost of sand and stone	1,017.63	.204	741.00	.1050	1,622.01	.2897
Cost of cement	1,547.15	.309	2,307.90	.3246	1,551.17	.2772
Expansion joints	48.67	.010	112.40	.0156	206.74	.0369
Coal and oil for mixer, and miscellaneous supplies	30.75	.006	25.00	.0034	119.19	.0213
Forms and other lumber	35.00	.007	31.75	.0047	18.33	.0033
Filling expansion joints next to curbs	45.18	.010				
Reinforcing steel			100.00	.0140		
Excavation			591.73	.0840		
Trimming shoulders					211.38	.0378
Totals	3,964.02	.793	5,803.07	.8176	5,794.76	1.0352

Dimensions of pavements, length of haul for materials, and cost of cement and amount used per square yard.

Project No. 1:

Area of pavement laid	square yards	5,000
Thickness of pavement	inches	6
Width of pavement	feet	45
Length of haul for materials	mile	⅛
Cost of cement per barrel	dollars	1.06
Amount of cement used per square yard	barrel	.29

This is a one-course pavement for which the coarse aggregate was gravel mixed with a small amount of Joliet crushed stone. The conditions under which the pavement was constructed appear to have been favorable. The cost is low.

Project No. 2:

Area of pavement laid	square yards	7,111
Thickness of pavement	inches	6½
Width of pavement	feet	16
Length of haul for materials	miles	1½
Cost of cement per barrel	dollar	.98
Amount of cement used per square yard	barrel	.33

This is a one-course pavement. The sand and crushed stone were both obtained free and the only charges were for freight. A newly filled sewer trench made it necessary to cross-reinforce a small part of the pavement with ½-inch square twisted bars, 6 feet long and 12 inches center to center. The cost of this section, exclusive of grading, was only $0.7336 per square yard. This low cost was largely due to the free sand and crushed stone.

Project No. 3:

Area of pavement laid	square yards	5,594
Thickness of pavement	inches	7
Width of pavement	feet	18
Length of haul for materials	mile	⅛
Cost of cement per barrel	dollars	1.025
Amount of cement used per square yard	barrel	.29

This is a one-course pavement, and the coarse aggregate consisted of gravel. Armored expansion joints were used. The thickness varies from 8 inches at the center to 6 inches at the side. Congestion of traffic caused some expense and delay. The cost, however, is only moderate.

MAINTENANCE.

The shoulders, slopes, and drainage structures of concrete roads require the same kind of maintenance as other types of improved roads and will, therefore, not be given special attention here. The maintenance of the pavement consists, for the most part, in repairing cup holes, cracks, contraction joints, and perhaps the renewal of an occasional defective area.

Cup holes are spots in the surface of the pavement which break down under traffic and which may result from any one of a number of causes. The most frequent cause for such defects is the presence

of sticks, lumps of clay, particles of unsound stone, or other objectionable material in the aggregates. When cup holes first appear they are usually from 1 to 2 inches in diameter and from ½ to 1 inch in depth, but they become gradually enlarged by the action of traffic in loosening and abrading the concrete around their edges, and unless promptly repaired they may soon have an area of several square feet and a considerable depth. The action of traffic also gradually breaks away the concrete at the edges of cracks and joints, and if proper maintenance is not provided a considerable area of the surface of the pavement will be destroyed. The maintenance of cup holes, cracks, and joints usually consists of filling them with tar and covering the tar with coarse sand, pea gravel, or stone chips. Satisfactory results can be secured by this method only when a crew with proper equipment and materials goes over the road making necessary repairs at least two or three times a year.

Where defects of any considerable size are to be repaired the edges should be chiseled down until they are approximately vertical and not less than about 1 inch deep. The hole should be thoroughly cleaned and painted with tar, after which it should be filled with clean, coarse stone chips thoroughly grouted with tar. The surface of the patch should then be covered with coarse sand, pea gravel, or fine stone chips.

Either refined water-gas or coal-gas tar may be used for making such repairs, and the Office of Public Roads has obtained satisfactory results with both kinds. There is some difference of opinion among engineers as to just what consistency the tar should possess in order to give the best results, but the most general requirement in this particular seems to be that the tar when subjected to the float test in water at 50° C. will permit the float to sink in about 100 seconds. In order to apply a tar of this kind satisfactorily it is necessary that it be heated to about 225° F.

The repair equipment may consist of a small portable tar kettle, a horse and cart, pouring pots, wire brooms, hammers, and stone chisels.

When it becomes necessary to renew any portion of the pavement with Portland cement concrete that portion should be entirely closed to traffic, and the concrete should be mixed, placed, and cured in the manner described in the discussion of construction. The edges of the old concrete should be thoroughly cleaned and coated with neat cement mortar before the new concrete is placed.

A properly constructed concrete pavement ought to wear down uniformly and develop few defects. Poorly constructed and poorly maintained contraction joints are probably responsible for more defects of the kind described than can be attributed to any other one

cause. For this reason the contraction joints should be given very careful attention at the time of construction.

It has been claimed that the difficulty involved in properly maintaining defects in joints and cracks and the inconvenience attending periodic renewals of the pavement may be largely eliminated by maintaining a bituminous wearing surface over the concrete. Until further improvements are made in this method of treating concrete pavements, however, no specific recommendations can be made.

CONCLUSION.

In concluding this discussion of concrete roads the principal points may be summarized as follows:

(1) The economic efficiency of concrete roads is undetermined at present, but the indications are that this type of construction will prove to be well suited for certain conditions.

(2) The one-course type of concrete pavement is greatly to be preferred to the two-course type, but there are conditions under which the adoption of the two-course type of construction may be justified.

(3) The proportion of cement to the sand and coarse aggregate combined should not be less than about 1 to 5, and the proportion of sand to coarse aggregate should not be less than $1\frac{1}{2}$ to 3, nor greater than 2 to 3. Ordinarily, when gravel is used as coarse aggregate, the proportions may be made 1 part of cement to $1\frac{1}{2}$ parts of sand to 3 parts of gravel, and when crushed stone is used as coarse aggregate, 1 part of cement to $1\frac{3}{4}$ parts of sand to 3 parts of crushed stone.

(4) All types of contraction joints which have yet been devised require careful and frequent attention in order to prevent rapid deterioration of the pavement in their vicinity. It appears that better results are obtained by spacing the joints at an angle of about 75° to the center line of the road than when they are placed at an angle of 90°.

(5) Thin bituminous wearing surfaces for concrete pavements can not be economically justified at present. It is possible that through experimental investigations some method of constructing such surfaces to give uniformly satisfactory results may yet be devised. If this is done, the maintenance of concrete pavements and the contraction-joint problem will be greatly simplified.

(6) Intelligent engineering supervision is absolutely essential in concrete pavement construction, because defective materials or workmanship can not be readily repaired after the pavement is completed, and they are not usually apparent until the pavement has been in use for some time.

(7) It is believed that the following specifications typify the best practice which has been developed in concrete pavement construction.

It should be borne in mind, however, that some of the requirements which they contain are necessarily tentative and will probably be modified as experience demonstrates what methods of construction produce the best results.

APPENDIX.

Typical Specifications for Grading, Building all Necessary Drainage Structures, and Surfacing With Concrete the ——— Road.

LOCATION.

The work referred to in these specifications is to be done on the ------ road, beginning at ------ and extending in a ------ direction through ------ to ------, a distance of ------ miles.

WORK TO BE DONE.

The contractor shall do all clearing and grubbing, make all excavations and embankments, do all shaping and surfacing, construct all drainage structures and other appertaining structures, move all obstructions in the line of the work, and, unless otherwise provided in these specifications, shall furnish all equipment, materials, and labor for the same. In short, the contractor shall build said road in strict accordance with the plans and specifications and shall leave the work in neat and finished condition.

PLANS AND DRAWINGS.

The plans, profiles, cross sections, and drawings on file in the office of ------ at ------ show the location, profile, details, and dimensions of the work which is to be done, and shall be considered as a part of these specifications. The work shall be constructed according to the above-mentioned plans, profiles, cross sections, and drawings. Any variation therefrom, as may be required by the exigencies of construction, will in all cases be determined by the engineer. On all drawings figured dimensions are to govern in cases of discrepancies between scale and figures.

GRADING.

Grading shall include all excavating, filling, borrowing, trimming, picking down, shaping, sloping, and all other work that may be necessary in bringing the road to the required grade, alignment, and cross section; the clearing out of waterways and old culverts; the excavation of all necessary drainage and outlet ditches; the grading of a proper connection with all intersecting highways; the grubbing up and clearing away of all trees, stumps, and boulders within the lines of the improvement, and the removal of any muck, soft clay, or spongy material which will not compact under the roller so as to make a firm unyielding subgrade.

All trees, stumps, and roots within the limits of the improvement shall be grubbed up so that no part of them shall be within six (6) inches of the surface of the ground or within eighteen (18) inches of the surface of the subgrade, except that, if they occur in an area to be covered by a fill more than eighteen (18) inches in depth, they shall be grubbed up or cut off even with the present surface of the ground.

Embankments shall be formed of good sound earth or stone and carried up full width. The material shall be deposited in layers not more than one (1) foot in thickness and each layer shall be rolled until thoroughly compacted

with a roller weighing not less than ten (10) tons. All existing slopes and surfaces of embankments shall be plowed or scarified where additional fill is to be made, in order that the old and new material may bond together. When sufficient material is not available within the fence lines to complete the embankments, suitable borrow pits from which the contractor must obtain the necessary material will be designated by the engineer. If there is more material taken from the cuts than is required to construct the embankments, as shown on the plans, the excess material shall be used in uniformly widening the embankments or shall be deposited where the engineer may direct. Where embankments are formed of stone, the material shall be carefully placed so that all large stones shall be well distributed and the interstices shall be completely filled with smaller stone, earth, sand, or gravel, so as to form a solid embankment.

During the work of grading, the sides of the road shall be kept lower than the center and the surface maintained in condition for adequate drainage.

The grading of any portion of the road shall be complete before any surfacing material is placed on that portion, and where the plans do not call for any substantial change in the grade of any existing section of the road, the surface shall be completely scarified to a depth of three (3) inches or more before the subgrade is prepared.

All excavated material[1] will be classed as earth and rock. Only rock in place which requires blasting for its removal and boulders of one-half cubic yard or more in volume will be classed as rock excavation.

Materials obtained from excavation and used in embankments will be paid for as excavation only, though the contractor is required to shape and trim the embankments properly. Materials obtained from excavation and used for surfacing will be paid for only once and at the price bid for surfacing material.

Quantities of materials moved in grading will be measured in excavation and the volumes determined by the average end area method, and no payment will be made for materials excavated outside the slope lines shown on the plans unless the additional excavation is ordered by the engineer.

The contract prices for excavation shall be compensation in full for all the work which is required to be done under the heading "grading," except that an additional allowance at the rate of one and one-half ($1\frac{1}{2}$) cents per cubic yard per one hundred (100) feet will be made for all materials of excavation necessarily hauled more than five hundred (500) feet. The centers of gravities of cuts and corresponding embankments will be used in determining the length of haul, and if the center of gravity of the cut is more than five hundred (500) feet from the center of gravity of the corresponding fill, overhaul will be allowed for the entire amount of material in the cut for the actual distance in excess of five hundred (500) feet.

DRAINAGE STRUCTURES.

[Insert technical specifications for necessary drainage structures.]

SUBGRADE.

The subgrade, or that portion of the road upon which the concrete surface is to be laid, shall consist of good sound earth brought to the proper elevation,

[1] In general, it is more satisfactory to classify the materials of excavation and to invite unit-price bids rather than lump-sum bids. However, if unit-price bids are invited, it is important that the various quantities be accurately determined in order that the best bid may be selected. If lump-sum bids are desired, omit the following paragraphs.

alignment, and cross section, and shall be rolled until firm and hard with a roller of the macadam type weighing not less than ten (10) tons and not more than fifteen (15) tons. Should earth be encountered which will not compact by rolling so as to be firm and hard, it shall be removed and replaced with suitable material, and that portion of the subgrade shall be again rolled. When the rolling is completed, the surface of the subgrade shall conform to the cross section shown on the plans and shall have the proper elevation and alignment, and shall be so maintained until the concrete surface is in place.

SHOULDERS.

The shoulders shall be partially built up at the time the subgrade is being prepared, and before the pavement is opened to general traffic they shall be carefully graded to the required cross section and shall be thoroughly compacted by rolling with a roller weighing not less than ten (10) tons and not more than fifteen (15) tons.

The contract price for shaping subgrade and shoulders shall be compensation in full for all work required of the contractor under the headings "Subgrade" and "Shoulders."

MATERIALS.

Cement.—The cement for use in this work shall meet the requirements of the United States Government specification for Portland cement, as published in Circular No. 33, United States Bureau of Standards, issued May 1, 1912.

All cement shall be held at least ten (10) days after sampling, before it is used in any part of the work. If the cement satisfactorily passes all tests that may be made within that time, it may be used, and the 28-day test will not be insisted upon, but if it should fail to pass satisfactorily any test made within that time, then the cement shall not be used until it has passed satisfactorily all tests, including the 28-day test. All cement shall be delivered on the work in cloth or paper bags containing ninety-four (94) pounds net weight, and this amount of cement shall be considered as having a volume of one (1) cubic foot. In order to allow ample time for inspecting and testing, the cement shall be stored in a suitable weather-tight building having the floor blocked or raised from the ground, and shall be stored so as to permit of easy access for proper inspection and so that each carload shipment may be readily identified.

Sand.—The sand for use in the concrete shall be composed of particles of hard, durable stone, and not more than three (3) per cent, by weight, of clay, loam, or silt. No clay, however, will be permitted if it occurs as a coating on the sand grains. The grains shall be of such sizes that all will pass a one-fourth (¼) inch mesh screen; that not more than twenty (20) per cent will pass a No. 50 sieve; and that not more than sixty (60) per cent nor less than twenty (20) per cent will be retained on a No. 20 sieve. The sand shall be of such quality that a mortar made in the proportion of one (1) part of cement to three (3) parts of the sand, according to standard methods, when tested at any age not exceeding twenty-eight (28) days, will have a tensile strength of at least one hundred (100) per cent of that developed in mortar of the same proportions made of the same cement and standard Ottawa sand. The cement used in these tests shall be from an accepted shipment of that proposed for use with the sand.

Gravel.—The gravel for use in the concrete shall be composed of hard, sound, durable particles of stone, and not more than one (1) per cent, by weight, of clay, loam, or silt. No clay, however, will be permitted if it occurs as a

coating on the particles of stone. The particles of stone shall be graded in size between those retained on a screen having circular openings three-eighths (⅜) inch in diameter (or a one-fourth (¼) inch mesh screen) and those passing a screen having circular openings one and one-half (1½) inches in diameter. Not less than twenty (20) per cent shall be retained on and not less than twenty (20) per cent shall pass a screen having circular openings three-fourths (¾) inch in diameter. The gravel shall be free from particles of soft sandstone, shale, slate, coal, or other material which may readily disintegrate.

Crushed stone.—Crushed stone for use in the concrete shall be composed of particles of clean, sound, durable stone, crushed to such sizes that all will be retained on a screen having circular openings three-eighths (⅜) inch in diameter (or a one-fourth (¼) inch mesh screen) and will pass a screen having circular openings one and one-half (1½) inches in diameter. Not less than twenty-five (25) per cent shall be retained on and not less than twenty-five (25) per cent shall pass a screen having circular openings three-fourths (¾) inch in diameter.

Samples of the stone when subjected to the hardness, toughness, and abrasion tests, as described in United States Office of Public Roads Bulletin No. 44, shall satisfactorily meet the following requirements:

Hardness, not less than ten (10); toughness, not less than eight (8); and per cent of wear, not more than four (4).[1]

Water.—The water used in mixing the concrete shall be free from oil, acid, alkali, and vegetable matter, and fairly free from clay or silt.

CONSTRUCTION.

Mixing and placing concrete.—Upon the subgrade, prepared as herein specified, shall be laid a concrete surface of the width, thickness, and cross section shown on the plans. The subgrade shall be wet but not muddy when the concrete is placed upon it. The concrete shall be composed of the following materials proportioned by volume: One (1) part of cement, one and one-half (1½) parts of sand, three (3) parts of gravel, and sufficient water to form a quaky mass; or one (1) part of cement, one and three-quarters (1¾) parts of sand, three (3) parts of crushed stone, and sufficient water to form a quaky mass. The materials shall be thoroughly mixed in a machine mixer of the batch type, so designed, constructed, and operated that the thorough mixing of the materials is assured and that the consistency of all batches is the same. The operations of transporting the concrete from the mixer to its proper place in the road and of spreading and tamping it in place shall be so conducted as not to cause or permit any separation of the materials of the concrete. The concrete shall be placed between the forms, hereinafter described, and the surface shall then be shaped, true to grade and to a cross section having one-fourth (¼) inch more crown than that shown on the cross-section drawings by means of a well-constructed "strike board." When the concrete is thus shaped, it shall be tamped until mortar flushes to the surface in such quantity as to fill completely all the voids between the particles of the coarse aggregate. The tamping shall be done with a template having a face not less than six (6) inches in width and conforming with the crown shown on the cross-section drawings, or by some other device equally as satisfactory to the engineer. When the tamp-

[1] Stone of only fair quality will meet the above requirements for hardness, toughness, and per cent of wear, and if better stone is available these requirements should be such as to insure its use. It is also desirable to list the available varieties of stone which would be acceptable.

ing is completed, the surface of the concrete shall be finished by floating it with wooden floats. The finished surface shall be free from porous or open spots. No portion of it shall be more than one-half (½) inch below a template, cut to the crown shown on the cross-section drawings, placed on the pavement at right angles to the center line of the road, and no portion of it shall be more than one-half (½) inch below a straightedge ten (10) feet in length or more than one-fourth (¼) inch below a straightedge three (3) feet in length, laid on the pavement parallel to the center line of the road.

Protection.—After the concrete surface has been finished, as above described, it shall be entirely covered with canvas as soon as this can be done without marring its surface. The canvas shall be kept wet until the concrete has set to such an extent that the surface of the pavement will not be marred by men walking upon it (about twenty-four (24) hours), and it shall then be removed. Immediately after the canvas has been removed, the surface of the concrete shall be covered with a two (2) inch layer of earth, which shall be thoroughly wet with water immediately after it is placed upon the concrete, and shall remain in place and be kept wet with water for at least two (2) weeks. It shall be removed before traffic is permitted upon the concrete surface. During this period of two weeks or longer, as the engineer may require, on account of weather conditions, no traffic whatever shall be allowed upon the concrete.

Forms.—The forms shall be smooth, clean, free from warp, of sufficient strength to resist springing out of shape, of a width equal to the edge thickness of the pavement, and so designed that the various sections may be fastened together in such a manner as to prevent relative vertical movement of the ends. The forms shall be set true to line and grade, shall be well staked and braced, and shall have a firm bearing.

Joints.—Joints shall be spaced thirty (30) feet apart where gravel is used as coarse aggregate and fifty (50) feet apart where crushed stone is used as coarse aggregate. They shall be perpendicular to the subgrade, extend entirely through the concrete pavement, and be located at an angle of seventy-five (75) degrees with the center line of the road. The joint shall be one-fourth (¼) inch in width, and the abutting ends of the concrete sections shall be separated by asphaltic or tar felt one-fourth (¼) inch in thickness extending the full width and depth of the pavement. The surface of the concrete pavement on each side of the joint shall be true to grade and cross section.

The contract price for the concrete pavement shall be compensation in full for furnishing all materials, laying, sprinkling, and protecting the concrete, furnishing and setting all forms, constructing necessary contraction joints, and doing all other incidental work.

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